



ORIGINAL ARTICLE

Analysis of cataract surgery induced astigmatism: Two polar methods comparison



Veronica García-López^{a,b}, Claudia García-López^{a,b}, Victoria de Juan^{b,c}, Raul Martin^{a,b,d,*}

^a Universidad de Valladolid, Instituto Universitario de Oftalmobiología Aplicada (IOBA), Paseo de Belén, 17 – Campus Miguel Delibes, 47011 Valladolid, Spain

^b Optometry Research Group, IOBA Eye Institute, School of Optometry, University of Valladolid, Valladolid, Spain

^c Department of Ophthalmology, Hospital Universitario Ramon y Cajal, 28034 Madrid, Spain

^d School of Health Professions, Plymouth University, Derriford Road, Plymouth PL6 8BH, UK

Received 10 June 2016; accepted 9 November 2016

Available online 28 December 2016

KEYWORDS

Surgical induced astigmatism (SIA);
Polar value analysis;
Toric IOL;
Corneal incision

Abstract

Purpose: Surgically induced astigmatism (SIA) caused by the incision after cataract surgery may be calculated to improve IOL toric power calculation and achieve better visual outcome. SIA could be determined as the difference between preoperative and postoperative keratometry expressed in polar values using different equations. The objective of this study is to compare the SIA calculated with two different polar value analysis methods [Method #1: KP (90)/KP (135) developed to be used with incisions placed at 90° and Method #2: AKP/AKP (+45) developed to be used independently of the incision location].

Methods: Preoperative and one month postoperative data of 210 cataractous eyes (131 patients) undergoing uncomplicated cataract surgery were assessed. All incisions were performed at 11 o'clock (120°). No sutures were used in any patient. IOLMaster (Carl Zeiss Meditec, Dublin, Ireland) keratometry was used to polar calculation.

Results: The average age was 66.25 ± 12.33 years (range 22–89). SIA polar value data calculated with Method #1 were KP (90) $-0.06 \pm 0.52D$ and KP (135) $+0.05 \pm 0.91D$ and calculated with Method #2 were AKP $-0.10 \pm 0.87D$ and AKP (+45) $+0.02 \pm 0.02D$. However, SIA value represented in traditional notation (diopters@axis in degrees) was the same value independently of the method used to calculate; $+0.65@110.70^\circ$.

Conclusion: SIA value is independent of the polar method used to its calculation and slight variations in the incision position could be accepted without clinical relevant impact in SIA magnitude. Both methods [Method #1: KP (90)/KP (135) and Method #2: AKP/AKP (+45)] are useful to calculate SIA with superior incisions at 120°.

© 2016 Spanish General Council of Optometry. Published by Elsevier España, S.L.U. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

* Corresponding author at: School of Health Professions, Faculty of Health and Human Sciences, Plymouth University, Peninsula Allied Health Centre, Derriford Road, Plymouth PL6 8BH, UK and Optometry Research Group, IOBA Eye Institute, School of Optometry (University of Valladolid). Valladolid, Spain.

E-mail address: raul@ioba.med.uva.es (R. Martin).

<http://dx.doi.org/10.1016/j.optom.2016.11.001>

1888-4296/© 2016 Spanish General Council of Optometry. Published by Elsevier España, S.L.U. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

PALABRAS CLAVE

Astigmatismo quirúrgicamente inducido (SIA);
Análisis del valor polar;
Lente de contacto tórica;
Incisión corneal

Análisis del astigmatismo inducido en la cirugía de cataratas: comparación de dos métodos polares**Resumen**

Objetivo: El astigmatismo quirúrgicamente inducido (SIA) causado por la incisión tras la cirugía de cataratas se puede calcular para mejorar el cálculo de la potencia de las lentes intraoculares tóricas y lograr un mejor resultado visual postquirúrgico. El SIA puede determinarse como la diferencia entre la queratometría preoperatoria y postoperatoria expresada en valores polares, utilizando diferentes ecuaciones. El objetivo de este estudio fue comparar el SIA calculado mediante dos métodos de análisis de valores polares [Método 1: KP (90)/KP (135) desarrollado para ser utilizado con incisiones situadas a 90 grados, y Método 2: AKP/AKP(+45) desarrollado para ser utilizado independientemente del lugar de la incisión].

Métodos: Se analizaron los datos preoperatorios y postoperatorios tras un mes de cirugía de catarata no complicada, de 210 ojos (131 pacientes). Todas las incisiones se realizaron a las 11 en punto (120 grados). No se realizaron suturas en ningún paciente. Se utilizó la queratometría proporcionada por el sistema IOLMaster (Carl Zeiss Meditec, Dublín, Irlanda) se empleó para realizar el cálculo polar.

Resultados: La edad media fue de $66,25 \pm 12,33$ años (rango de 22 a 89). Los datos de los valores polares del SIA calculados con el Método 1 fueron KP(90) $-0,06 \pm 0,52D$ y KP(135) $+0,05 \pm 0,91D$, y los calculados con el Método 2 fueron AKP $-0,10 \pm 0,87D$ y AKP(+45) $+0,02 \pm 0,02D$. Sin embargo, el valor SIA representado en la notación tradicional (dioptrías@ejes en grados) fue el mismo, independientemente del método de cálculo utilizado; $+0,65@110,70^\circ$.

Conclusión: El valor SIA es independiente del método polar utilizado para su cálculo, pudiendo aceptarse ligeras variaciones en el lugar de incisión, sin impacto clínico relevante en cuanto a la magnitud del SIA. Ambos métodos [Método 1: KP (90)/KP (135) y Método 2: AKP/AKP(+45)] son útiles para calcular el SIA con incisiones superiores localizadas a 120 grados.

© 2016 Spanish General Council of Optometry. Publicado por Elsevier España, S.L.U. Este es un artículo Open Access bajo la licencia CC BY-NC-ND (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Nowadays, cataract surgery with implantation of an intraocular lens (IOL) is the most common ophthalmic surgical procedure.¹ Over the past years, surgical technique has evolved from standard extracapsular to micro incision without suture. Also, the formulas and devices that calculate the IOL power have experimented an important advance. These progresses have allowed cataract surgery to be a less invasive procedure, with better and more predictable refractive results. So that, most patients have increased expectations about cataract surgery result.^{2,3}

For this reason, toric IOLs have been developed to improve the refractive outcome in patients with astigmatism. To accurate toric IOL power calculation is necessary to know not only the preoperative astigmatism, axial length, etc. as standard IOL calculations, but also the surgically induced astigmatism (SIA) caused by the incision. SIA must be added to the preoperative measured corneal astigmatism using vector analysis.⁴⁻⁶ Thus, it would be possible to elucidate the total astigmatism that is necessary to correct with the IOL⁷ and improve visual outcome of the surgery. SIA could be calculated as the change in corneal astigmatism using keratometry values.

The objective of this study was to compare induced astigmatism as the change in the keratometry (measured with IOLMaster) pre and post cataract surgery, with two

different ways to conduct the polar value analysis [Method #1: KP (90)/KP (135) proposed to be used with incisions placed at 90° and Method #2: AKP/AKP (+45) proposed to be used independently of the incision location]. These results will be of great utility to clarify the controversy about what method to choose to calculate SIA.

Patients and methods

This prospective and comparative study included two visits: the baseline visit, before cataract surgery, and one month postoperatively.

Subjects

This study included 210 cataractous eyes of 131 patients (54.96% female) attending the IOBA-Eye Institute, University of Valladolid, Spain, scheduled to undergo phacoemulsification to remove cataract.

Exclusion criteria included patients with significant pathology that could influence the refraction such as diabetic retinopathy, corneal dystrophy, past or present keratitis, corneal leucomas affecting the visual axis, corneal degenerations, corneal ectasias, or uveitis. Subjects with a history of eye surgery and those having combined procedures at the time of cataract surgery, and cases requiring surgical suturing or developing inflammation that did not

correspond to the natural course of postoperative healing were also excluded.

After explaining the details of the study, written informed consent was obtained from all patients before enrolment. The study was approved by the Human Sciences Ethics Committee of the University of Valladolid and was carried out in accordance with the Declaration of Helsinki.

Study visits

Preoperative and one month postoperative complete eye examination were conducted; including uncorrected and corrected distance visual acuity assessment, auto-refraction, biometry, slit lamp biomicroscopy, Goldman tonometry and indirect ophthalmoscopy with pupil mydriasis.

Cataract surgery was performed by the same experienced surgeon, making a 2.75 mm clear corneal incision at 11 o'clock position (around 120°), and clear corneal paracentesis was performed at 1 o'clock position. An aspheric acrylic posterior chamber IOL Acrysof natural IQ SN60WF (Alcon Cusí S. A. El Masnou, Barcelona, Spain) was implanted. When the IOL power was lower than 6.50D, Acrysof Multipiece MA60MA (Alcon Cusí S. A. El Masnou, Barcelona, Spain) was implanted. The corneal wound was hydrated and no sutures were used in any patient.

Instrumentation

Pre and post autorefraction were measured with ARK-30 autorrefractor (Nidek Co. LTD, Aichi, Japan). Keratometry was conducted with the IOLMaster (Carl Zeiss Meditec, Dublin, Ireland). IOLMaster uses six light reflections projected on the anterior cornea surface in an area of approximately 2.5 mm of diameter, depending on the corneal curvature, to measure main meridians keratometry. Three measurements were performed by the same experienced operator and mean value was taken like final value. A difference of 0.25 D or less between three readings in both main meridians was used as validation criteria.

Statistical analysis

Statistical analysis was performed using the SPSS 14.0 (SPSS Chicago, IL, EEUU) statistical package for Windows. A descriptive analysis of keratometry and polar values calculated with two different approaches [Method #1: KP (90)/KP (135) and Method #2: AKP/AKP (+45)] have been conducted. Pre and postoperative corneal astigmatism has been represented in a polar graph.

Polar value analysis

Polar value analysis was performed to calculate the SIA. The general expressions^{4,5,7,8} for the polar value method are:

Meridional or on – axis KP

$$= M\{\sin^2[(\alpha + 90) - \Omega] - \cos^2[(\alpha + 90) - \Omega]\} \quad (1)$$

Oblique or torqued KP

$$= M\{\sin^2[(\alpha + 45) - \Omega] - \cos^2[(\alpha + 45) - \Omega]\} \quad (2)$$

where Ω symbolize the plane analyzed, M is the magnitude of the net astigmatism reported in diopters (D) and α the meridian of net astigmatism in degrees (°).⁹

To calculate the polar values, it is possible to use different equations by changing Ω in expression (1) and (2). The following equations are the most frequently employed.⁵

Method #1:

$$KP (90) = M[\sin^2(\alpha) - \cos^2(\alpha)] \quad (3)$$

$$KP (135) = M[\sin^2(\alpha - 45) - \cos^2(\alpha - 45)] \quad (4)$$

This equation, among other applications, is used for incisions located around the 90° meridian.⁵ As incision in all our patients was placed at 11 o'clock (120°) we have chosen this equations due to the incision is close to 90°.

Method #2:

$$AKP = M\{\sin^2[(\alpha + 90) - \Omega] - \cos^2[(\alpha + 90) - \Omega]\} \quad (5)$$

$$AKP (+45) = M\{\sin^2[(\alpha + 45) - \Omega] - \cos^2[(\alpha + 45) - \Omega]\} \quad (6)$$

Replacing Ω by the incision meridian orientation (120°), the AKP and AKP (+45) were calculated with these expressions:

$$AKP = M\{\sin^2[(\alpha + 90) - 120] - \cos^2[(\alpha + 90) - 120]\} \quad (7)$$

$$AKP (+45) = M\{\sin^2[(\alpha + 45) - 120] - \cos^2[(\alpha + 45) - 120]\} \quad (8)$$

This variation is recommended for any procedure⁵ independently of the incision location. So, these equations may be suitable to use in our patients.

Finally, SIA expressed as polar values was calculated with the difference between the postoperative and preoperative polar values⁷ calculated with both methods. SIA calculated with each method has been represented in a polar graph.

The meridional polar values, KP (90) or AKP, indicate the flattening or steepening of the surgical meridian.⁵ A positive polar value expresses a steepening of the surgical meridian, a with-the-rule (WTR) change, while a negative result a flattening or against-the-rule (ATR) change. The polar values of the oblique meridian, KP (135) or AKP (+45), expresses the surgically induced torque of the cylinder. A positive polar value signifies an anticlockwise torque and a negative result a clockwise torque.

It is possible to transform the polar values to conventional astigmatism notation (diopters@axis in degrees) by using the following equations.^{5,9}

With Method #1:

$$M = \pm \sqrt{KP (90)^2 + KP (135)^2} \quad (9)$$

$$\alpha = \arctan \left(\frac{M - KP(90)}{KP(135)} \right) + p180 - 90 \quad (10)$$

where p is an integer.

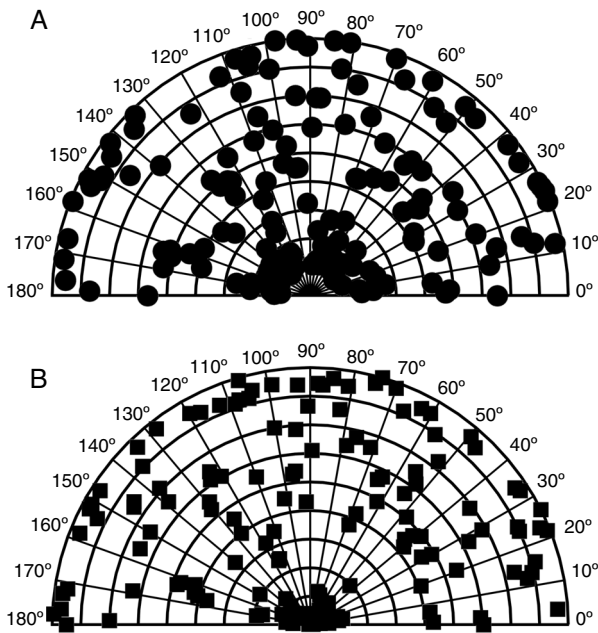


Figure 1 Polar representation of preoperative (A) and post-operative (B) astigmatism (diopters) measured with IOLMaster keratometry.

And with Method #2 values:

$$M = \pm \sqrt{AKP^2 + AKP (+45)^2} \tag{11}$$

$$\alpha = \arctan \left(\frac{M - AKP}{AKP (+45)} \right) - 90 \tag{12}$$

Results

The average age was of 66.25 ± 12.33 years (range 22–89). Mean preoperative spherical equivalent was $-3.38 \pm 6.52D$ (sphere $-2.97 \pm 6.35D$ and cylinder $-1.40 \pm 1.07D$) and keratometry was $43.55 \pm 1.64D$ in flatter meridian and $44.66 \pm 1.67D$ in steeper corneal meridian with $1.11 \pm 0.83D$ of preoperative corneal astigmatism. After surgery mean spherical equivalent was $-0.47 \pm 0.85D$ (sphere $-0.04 \pm 0.93D$ and cylinder $-0.85 \pm 0.59D$) and keratometry was $43.56 \pm 1.62D$ in flatter meridian and $44.76 \pm 1.76D$ in steeper corneal meridian with $1.20 \pm 1.11D$ of postoperative corneal astigmatism. Fig. 1 shows vector representation of corneal astigmatism pre and post cataract surgery. The polar value data calculated with both polar methods and SIA are summarized in Table 1. Using Method #1 and Method #2 the same SIA (expressed in conventional notation diopters@axis in degrees) value was achieved; $+0.65 @ 110.70^\circ$ (Fig. 2).

Discussion

The classical spherocylinder format written as sphere, cylinder and axis is useful for a single analysis but is not appropriate for mathematical and statistical analysis of aggregate data.⁵ The cylindrical component is characterized by a magnitude expressed in diopters and a direction in degrees.^{5,10} Thus, it is necessary to use a method able

Table 1 Summary of polar value results calculated with Method #1 and Method#2. Mean \pm SD (minimum to maximum value) in Dioptres are summarized pre and post-surgery. SIA, surgical induced astigmatism.

	Method #1		Method #2	
	KP (90)	KP (135)	AKP	AKP (+45)
Postop	-0.34 ± 1.20 (-4.17 to +4.67)	$+0.08 \pm 1.06$ (-10.38 to +1.76)	$+1.00 \pm 1.15$ (-0.75 to 9.47)	$+0.02 \pm 0.59$ (-1.06 to 4.62)
Preop	-0.28 ± 1.17 (-4.34 to +4.50)	$+0.03 \pm 0.68$ (-2.32 to +2.07)	$+1.10 \pm 0.83$ (-0.49 to +4.85)	$+0.00 \pm 0.00$ (0.00 to 0.00)
SIA	-0.06 ± 0.52 (-1.78 to +1.56)	$+0.05 \pm 0.91$ (-1.28 to +1.22)	-0.10 ± 0.87 (-2.18 to +1.74)	$+0.02 \pm 0.02$ (-1.06 to 4.62)

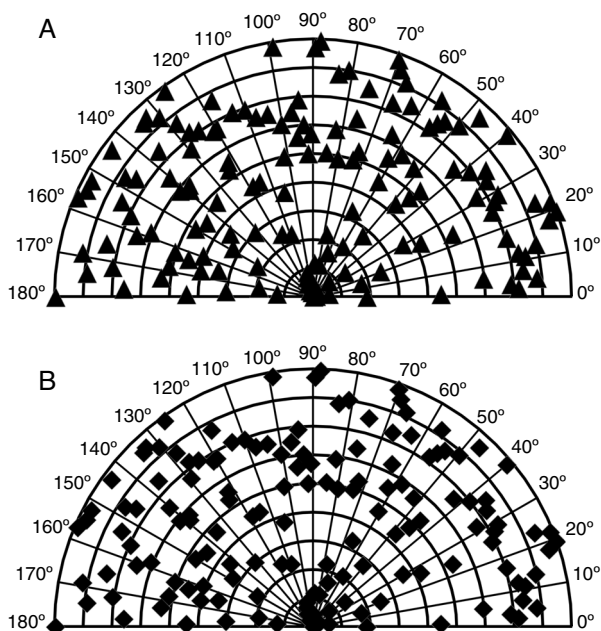


Figure 2 Polar representation of SIA (diopters) calculated with Method #1 KP (90)/KP (135) (A) and with Method #2: AKP/AKP (+45) (B). SIA, surgical induced astigmatism.

to manage this type of data, such as the polar value analysis.^{4,5,7-10}

The astigmatism is represented by two polar values. One possible application of this calculation is to describe the astigmatic change following cataract surgery. Naeser et al.⁹ have developed and described the equations required to calculate the polar values mentioned. In another study⁵ they described the uses of the different polar values. Varying Ω in Eqs. (1) and (2) it is possible to obtain the different polar values, of which the most commonly used are those already mentioned in Eqs. (3)–(6).

The KP (90) and KP (135) are used for superior incisions, located around the 90° meridian, and also for the analysis of refractive data population and spectacle prescriptions.⁵ The AKP and AKP (+45) are usually used for analysis of an incision disposed in the preoperative steeper meridian, or indeed any procedure with the objective of reducing the steep meridian.⁵ So, it is expected no difference using both methods in the same patients undergoing cataract surgery with the incision at vertical meridian, as we enrolled in this study.

Naeser⁹ reported not significant difference in the flattening [change in KP (90) of 0.52D] induced by two different surgical techniques in 24 eyes after uncomplicated cataract surgery with corneal or scleral incision; however torque value [change in KP (135) of 0.77D] showed statistical significant differences.

SIA polar calculation is useful to assess the effect of corneal incision length. Large incisions induce high SIA than small incisions. Naeser⁷ reported near of 1.00D vertical flattening [KP (90)] and 0.50D of counterclockwise torque [KP (135)] with 9.0-mm superior incision ($p < 0.05$) against of a vertical flattening of 0.71D with 5.5-mm and 0.64 with 4.0-mm incisions and close to zero torque.

It is well known that SIA value vary between surgeons and patients because it is highlight influenced by location and size of the incision and by the individual biological

response of each patient's cornea.⁴ Moreover, some authors recommend develop customized equations taking into consideration the exact incision location¹¹ to obtain a precise result. However, our results suggests that slight variations in the incision location (around 120° instead 90° that Method #1 proposes) does not induce different SIA as achieve the same value expressed in conventional notation (diopters @ degrees). To the best of our knowledge this is the first report that compares the differences between two different polar methods to calculate SIA in the same sample of patients. These results could be useful to surgeons, eye care practitioners and researchers, helping to choose the method to calculate SIA and improve visual outcome after toric IOL surgery.

In our study we do not get the same polar SIA value with both methods analyzed. We noted that different flattening [KP (90) -0.06 D or AKP -0.10 D values] and different anticlockwise torque astigmatism [KP (135) $+0.11$ D or AKP (+45) $+0.59$ D] with either Method #1 or #2 (Table 1). These slight differences are related with the difference in the vector calculation because it is simply a projection onto two different meridians with each calculation method. These differences disappear to represent SIA with the conventional notation (astigmatism @ degree) (Fig. 2). These “apparent differences” in polar vectors results should be taken in account to make a correct data interpretation, because results of different studies that use different vector projection to calculate SIA could be non-interchangeable.

It should be noted that differences in keratometry data achieved with difference devices (IOLMaster, topographers or auto-keratometers) could induce any effect in SIA calculation and just devices with high repeatability and minimum operator dependency should be recommended to achieve sound data and improve toric IOL power calculation.⁶

Using anterior corneal keratometry to SIA calculation could be criticized after cataract surgery because these measurements do not take in account posterior corneal surface. However, on the posterior surface changes below of 0.1D has been described¹² so the effect of posterior corneal surface after cataract surgery in SIA calculation is of negligible clinical relevance.¹²

Other limitation of our study is the short follow-up period (one month after surgery), because other reports,^{7,13} suggest a change in the polar value data during the visits. However, refraction after uncomplicated cataract surgery is stable one week after surgery¹⁴ and corneal swelling after two weeks, so the follow up of our study has a minimum impact in our results and conclusions. Because all surgeries were performed by the same experienced surgeon lower SIA value than less-experienced surgeon, could be expected.

In conclusion, SIA value is independent of the polar method used to its calculation and slight variations in the incision position could be accepted without clinical relevant impact in SIA magnitude. Both methods [Method #1: KP (90)/KP (135) and Method #2: AKP/AKP (+45)] are useful to calculate SIA with superior incisions at 120°.

Conflicts of interest

None of the authors has a financial or proprietary interest in any material or method mentioned.

References

1. Acosta R, Hoffmeister L, Román R, Comas M, Castilla M, Castells X. Systematic review of population-based studies of the prevalence of cataracts. *Arch Soc Esp Ophthalmol*. 2006;81:509–516.
2. Narváez J, Zimmerman G, Stulting RD, Chang DH. Accuracy of intraocular lens power prediction using the Hoffer Q, Holladay 1, Holladay 2, and SRK/T formulas. *J Cataract Refract Surg*. 2006;32:2050–2053.
3. Gavin EA, Hammond CJ. Intraocular lens power calculation in short eyes. *Eye (Lond)*. 2008;22:935–938.
4. Alpíns NA. A new method of analyzing vectors for changes in astigmatism. *J Cataract Refract Surg*. 1993;19:524–533.
5. Naeser K, Hjortdal J. Polar value analysis of refractive data. *J Cataract Refract Surg*. 2001;27:86–94.
6. Ofir S, Abulafia A, Kleinmann G, Reitblat O, Assia E. Surgically induced astigmatism assessment: comparison between three corneal measuring devices. *J Refract Surg*. 2015;31:244–247.
7. Naeser K, Knudsen EB, Hansen MK. Bivariate polar value analysis of surgically induced astigmatism. *J Refract Surg*. 2002;18:72–78.
8. Naeser K, Behrens JK, Naeser EV. Quantitative assessment of corneal surgery: expanding the polar values concept. *J Cataract Refract Surg*. 1994;20:162–168.
9. Naeser K, Hjortdal JO. Bivariate analysis of surgically induced regular astigmatism. Mathematical analysis and graphical display. *Ophthalmic Physiol Opt*. 1999;19:50–61.
10. Naeser K. Conversion of keratometer readings to polar values. *J Cataract Refract Surg*. 1990;16:741–745.
11. Hashemi H, Khabazkhoob M, Soroush S, Shariati R, Miraftab M, Yekta A. The location of incision in cataract surgery and its impact on induced astigmatism. *Curr Opin Ophthalmol*. 2016;27:58–64.
12. Klijn S, van der Sommen CM, Sicam VA, Reus NJ. Value of posterior keratometry in the assessment of surgically induced astigmatic change in cataract surgery. *Acta Ophthalmol*. 2016;94:494–498.
13. Moon SC, Mohamed T, Fine IH. Comparison of surgically induced astigmatism after clear corneal incisions of different sizes. *Korean J Ophthalmol*. 2007;21:1–5.
14. De Juan V, Herreras J, Perez I, et al. Refractive stabilization and corneal swelling after cataract surgery. *Optom Vis Sci*. 2013;90:31–36.